

CONTAMINANT CONCENTRATIONS
IN BOTTOM SEDIMENTS
OF THE
SIR ADAM BECK POWER RESERVOIR
AND
NIAGARA RIVER BAR DREDGEATE

April 1987



Ontario

Ministry
of the
Environment

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**CONTAMINANT CONCENTRATIONS IN
BOTTOM SEDIMENTS OF
THE SIR ADAM BECK POWER RESERVOIR
AND NIAGARA RIVER BAR DREDGEATE**

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April, 1987**

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FOREWORD

The data presented in this report result from a joint program undertaken by the Ontario Ministry of the Environments' Great Lakes Section, Water Resources Branch and the Water Resources Assessment Section, West Central Region to determine: (i) the concentration and distribution of contaminants in sediments of Ontario Hydro's Sir Adam Beck Power Reservoir in Queenston; and (ii) the concentration of contaminants in material commercially dredged from the Niagara Bar at the outlet of the Niagara River.

The Reservoir sampling was carried out in anticipation of a recommendation which was to appear in the 1984 report of the Niagara River Toxics Committee (i.e. that samples be taken in both the Canadian and U.S. power reservoirs to determine if the bottom sediments constitute a potential source of contaminants to the lower Niagara River, and if so, what remedial action may be appropriate). Sampling of Niagara Bar dredged material stemmed from Regional concern over the chemical quality of material collected from an area potentially impacted by Niagara River contaminants and therefore its subsequent use, as well as the potential for resuspension of contaminants during dredging operations and their subsequent impact on Lake Ontario water uses.

A draft of this report and data were provided to the MOE Regional Office in October 1985 and a final draft was provided to the provincial-federal Niagara River work team during 1986 for their use in the preparation of the Niagara River Remedial Action Plan.

A final draft of this report has also been submitted to the International Joint Commission as part of the Ministry's contribution to the Niagara Task Force report (Water Quality Board Report - Appendix B) to be released in 1987.

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1.0 SUMMARY OF FINDINGS

In November, 1983 the Great Lakes Section and West Central Region of the Ontario Ministry of the Environment (MOE) conducted a survey to determine: i) the concentration and distribution of contaminants in sediments of Ontario Hydro's Sir Adam Beck Power Reservoir and, ii) the concentration of contaminants in material commercially dredged from the Niagara Bar at the outlet of the Niagara River. Samples were analyzed for inorganics (including arsenic and heavy metals), solvent extractables (oils and greases), PCBs, organochlorine pesticides, nutrients, percent loss on ignition and sediment particle size distribution.

Sir Adam Beck Power Reservoir

Bottom sediments in the Sir Adam Beck reservoir contained levels of arsenic, cadmium, chromium, copper, iron, lead, nickel, silver and zinc at levels in excess of the MOE guidelines for open water disposal of dredged sediments. When compared to the proposed MOE guidelines on the suitability of dredgeate for land disposal, the cadmium and lead concentrations in some samples would necessitate restricted land disposal. These findings suggest either relatively recent or ongoing upstream inputs of particulate-associated contaminants, since the latter were identified in surficial layers (top 3 cm). Due to the nature of water withdrawals for hydro-electric power generation, it is probable that the contaminants mainly originated in the Chippawa Channel and reached the reservoir via the Chippawa-Grass Island Pool diversion.

PCBs were also detected in 43% of the samples from the reservoir, but at levels (27-33 ng/g) close to the detection limit and below the open water dredged sediments disposal guideline. DDT and its metabolites DDE and DDD were the only organochlorine pesticides detected in reservoir sediments. However, they were present in the majority of samples, at concentrations ranging from 2 to 85 ng/g (DDT plus metabolites). The presence of these compounds may be due to recent (illegal) or past upstream use and subsequent losses to the aquatic environment, or possibly the use of other, DDT-containing insecticides such as dicofol. The above findings identify the need for follow-up investigations to: identify major sources of individual contaminants and to curtail their

inputs if still ongoing; to determine the mobility of reservoir sediments (ie. their susceptibility to resuspension) and the availability of their associated contaminants; and to allow calculation of the net loading of these contaminants to the lower Niagara River via the Sir Adam Beck power plant tailraces.

Niagara Bar Dredgeate

Samples of material dredged commercially from the Niagara Bar at the mouth of the Niagara River contained nutrients, inorganics, solvent extractables and organochlorines at concentrations which were considerably below the MOE guidelines for open water dredged spoils disposal and in most instances, lower than in fresh surficial sediments from the Bar. Since the latter contained some contaminants at levels above MOE dredging guidelines (eg. PCBs, iron) there is a need to determine the impacts of possible losses of particulate-associated contaminants during the dredging operation. Hexachlorobenzene was the only organochlorine compound detected in dredgeate samples (in one of three samples at 2 ng/g).

1.0 RÉSUMÉ DES RÉSULTATS

En novembre 1983, la Section des Grands Lacs et la Région du Centre-Ouest du ministère de l'Environnement de l'Ontario ont effectué une étude afin de déterminer : i) la concentration et la répartition des polluants contenus dans les sédiments du réservoir de la centrale Sir Adam Beck d'Ontario Hydro; et ii) la concentration des polluants contenus dans les matériaux dragués par une entreprise privée à l'endroit connu sous le nom de "Niagara Bar", à l'embouchure de la rivière Niagara. Les échantillons ont été analysés afin de déterminer la concentration de matières inorganiques (dont l'arsenic et les métaux lourds), de produits pouvant être extraits à l'aide d'un solvant (tels que huiles et graisses), de BPC, de pesticides organochlorés et de substances nutritives. Les analyses ont également porté sur la perte pondérale par combustion, exprimée en pourcentage, et sur la répartition des sédiments selon leur taille.

Le réservoir de la centrale Sir Adam Beck

Les concentrations d'arsenic, de cadmium, de chrome, de cuivre, de fer, de plomb, de nickel, d'argent et de zinc des sédiments se trouvant au fond du réservoir de la centrale Sir Adam Beck dépassaient les limites fixées par le ministère de l'Environnement pour l'élimination, dans les étendues d'eau libres, des sédiments dragués. Compte tenu des limites qu'a proposées le ministère en matière d'élimination des produits de dragage dans une décharge, les concentrations de cadmium et de plomb de certains échantillons sont telles qu'il faudrait restreindre ce type d'élimination. Ces résultats semblent indiquer des arrivées relativement récentes ou permanentes de polluants amenés, d'amont, par des particules, puisque ces polluants ont été retrouvés dans la couche superficielle (d'une épaisseur de 3 cm). En raison de la nature de l'alimentation en eau de la centrale hydro-électrique, il est probable que les polluants proviennent principalement du canal Chippawa et aient atteint le réservoir par le canal de dérivation Chippawa-Grass Island Pool.

Quarante-trois pour cent des échantillons prélevés dans le réservoir contenaient des BPC dont la concentration (de 27 à 33 ng/g) était proche du seuil de détection mais était inférieure à la limite fixée

pour l'élimination, dans les étendues d'eau libres, des sédiments dragués. Les seuls pesticides organochlorés dont on a détecté la présence dans les sédiments du réservoir sont le DDT et ses métabolites : le DDE et le DDD. Toutefois, dans la plupart des échantillons, leur concentration (DDT et métabolites) allait de 2 à 85 ng/g. La présence de ces composés peut être le résultat de leur utilisation récente (illégale) ou passée en amont avec contamination subséquente du milieu aquatique, ou encore de l'utilisation d'autres insecticides contenant du DDT, tels que le dicofol. Ces résultats démontrent clairement la nécessité d'effectuer d'autres études afin : d'identifier les sources principales de chaque polluant et d'en restreindre l'apport s'il a encore lieu; de déterminer la mobilité des sédiments dans le réservoir (c.-à-d. leur capacité de retourner en suspension) et la présence à l'état libre des polluants qu'ils véhiculent; et de calculer la charge nette de ces polluants dans la partie inférieure de la rivière Niagara à partir du canal de fuite de la centrale Sir Adam Beck.

Matériaux enlevés par dragage de la formation "Niagara Bar"

Les échantillons de matériaux enlevés par dragage de la formation "Niagara Bar", effectué par une entreprise privée à l'embouchure de la rivière Niagara, contenaient des substances nutritives, des matières inorganiques, des produits pouvant être extraits à l'aide d'un solvant, et des organochlorés. La concentration de ces diverses substances était bien inférieure aux limites fixées par le ministère en matière d'élimination, dans les étendues d'eau libres, des déblais de dragage et, dans la plupart des cas, inférieure à celle relevée dans les échantillons de sédiments superficiels de cette formation. Toutefois, comme ces derniers contenaient des polluants dont la concentration dépassait les limites fixées par le ministère pour les matériaux dragués (cas des BPC et du fer, par exemple), il faudra évaluer les répercussions de pertes possibles, lors du dragage, de polluants transportés par des particules. L'hexachlorobenzène est le seul composé organochloré dont on a relevé la présence dans les échantillons de matériaux dragués (dans un échantillon parmi trois, à une concentration de 2 ng/g).

2.0 INTRODUCTION

2.1 Ontario Water Uses and Contaminants Sources

An important management issue regarding the Niagara River is the diversion and use of water for hydro-electric power generation.

The Niagara Diversion Treaty, signed in 1950, established the flow-sharing arrangement for power generation which currently exists between Canada and the United States. At the same time, it provided for the preservation and enhancement of the beauty of the Falls. For example, the Treaty requires that during daylight hours of the tourist season (April 1 - October 31), a minimum flow of 2,830 m³/sec must be maintained over the Falls. At all other times, a minimum flow of 1,410 m³/sec is required. The remaining water, after municipal and industrial needs are met, is shared between Canada and the U.S. for power generation (Friesen, 1979; NRTC, 1984).

Five generating stations are located along the Canadian shore of the Niagara River with a maximum diversion capability of about 2,350 m³/sec (NRTC, 1984). The Canadian Niagara (80,000 kw)*, Ontario Power (135,000 kw) and Toronto Power (108,000 kw) stations, situated around the brink of the Horseshoe Falls, are now used only for peak power supply. Water intakes for these stations are in the Cascades area above the Falls, and water is discharged immediately below the Falls. In contrast, water is conveyed to the Sir Adam Beck generating stations Nos. 1 and 2 in Queenston from the Chippawa-Grass Island Pool area above the Falls via two 8.8 km long underground tunnels (up to 1,275 m³/sec) beneath the City of Niagara Falls and via the open-cut Queenston-Chippawa Power Canal (up to 660 m³/sec). Generating capacities of these two stations are 440,000 kw and 1,370,000 kw, respectively, and their tailraces discharge to the lower Niagara River at Queenston (Figure 1). The Power Canal also receives discharges from municipalities and industries located in the City of Niagara Falls and along the Welland River. These facilities as well as their inputs of contaminants are discussed in the Niagara River Toxics Committee report (NRTC, 1984). The entire flow of the Welland River (~20 m³/sec) is diverted into the Canal, where it

* designed generating capacity, in kilowatts (source: H-EPCO, 1961)

combines with the westward-flowing waters of Chippawa Creek (~ 640 m³/sec). (Chippawa Creek water is essentially Chippawa Channel water, with additional inputs from some Niagara Falls industries.)

During the night-time hours of the tourist season, additional water becomes available to Canada for power generation. This water is diverted, pumped up and stored in the power reservoir associated with the Sir Adam Beck generating stations (Figure 1). The pump-generating station and associated 300 hectare (750 acre) reservoir were completed in 1954 as an adjunct to Sir Adam Beck No. 2, to utilize any surplus energy during low power demand periods (H-EPCO, 1961). The water is subsequently released from the reservoir, (through the 170,000 kw pump generator station located at the outflow) during the daylight hours when power demand is higher. Similarly, additional water which is continuously available during the non-tourist season is stored in the reservoir during periods of low energy demand (generally nights and weekends) and released during periods of high energy demand.

Therefore, a sizeable proportion of the flow from the Ontario side of the upper Niagara River [most of it from the Chippawa-Grass Island Pool (J. C. Sands, Ontario Hydro, personal communication; H-EPCO, 1961)] may spend some time in the Sir Adam Beck Power Reservoir, which provides a relatively quiescent area in which at least a partial settling-out of suspended particulates can occur. For example, using particulate concentration data (MOE, 1983), the average daily load of suspended particulates carried by the Queenston-Chippawa Power Canal alone was about 500 kilograms/day in 1983. The quantity of particulates which enter the power reservoir would be expected to vary diurnally and seasonally, as well as with power needs and the source (quality) of the water.

Many hydrophobic contaminants, both inorganic and organic, can become adsorbed or attached to various types of inorganic or organic particles or aggregates (Hakanson, 1984) and, given sufficient time to settle out, these materials would tend to accumulate in the reservoir's bottom sediments. Similarly, the Robert Moses reservoir in New York State may also be a sink for contaminants originating further upstream on the

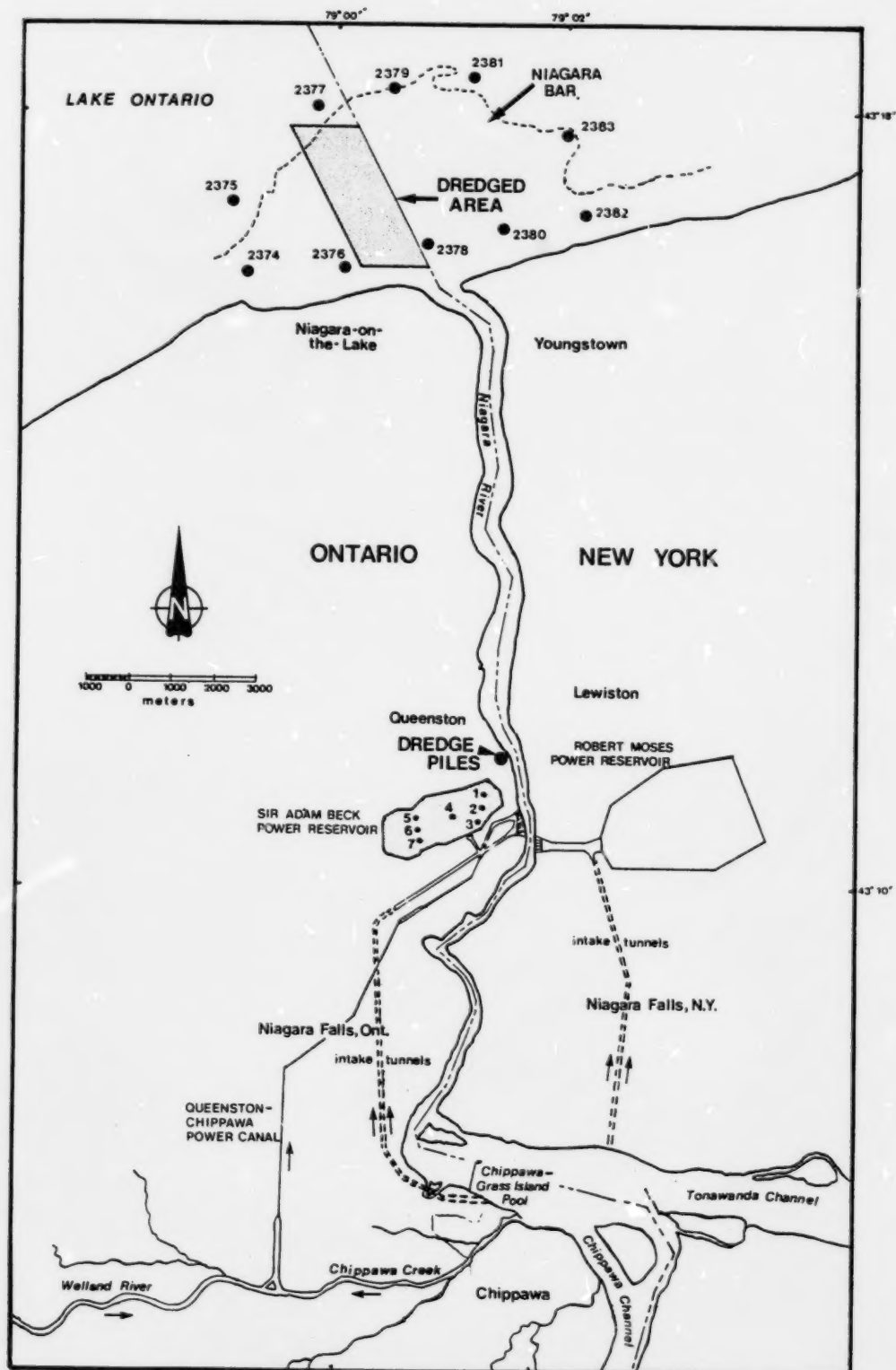


FIGURE 1 STUDY AREA SHOWING RESERVOIR, DREDGE PILES, DREDGED AREA AND NIAGARA BAR SAMPLING STATIONS

American side. Consequently, the Report of the Niagara River Toxics Committee (1984) recommended that sediment cores be taken in both power reservoirs and that they be radiodated and chemically analyzed to determine if the reservoirs' bottom sediments constitute a potential source of contaminants to the lower Niagara River, and if so, what remedial action may be appropriate.

2.2 Lower Niagara River Sediment Quality and Use

Previous investigations indicated that surficial sediments of the lower Niagara River are contaminated with a number of inorganic and organic contaminants (Kauss, 1983; Kuntz, 1984; NRTC, 1984). Furthermore, the river is a source of numerous inorganic and organic contaminants to Lake Ontario, and this loading is partly associated with suspended particulates (Kuntz, 1984; NRTC, 1984). Transport of suspended materials occurs in a number of directions across the Niagara Bar located just off the mouth of the Niagara River (Sly, 1983) and particles may settle in this area intermittently. Sediment in a portion of the Bar is commercially dredged by Ontario-Lake Erie Sand Ltd. under licence from the Ontario Ministry of Natural Resources (under the Beach Protection Act). Annual quantities dredged averaged $47 \times 10^3 \text{ m}^3$ during the period 1980 to 1982 (MNR data). This material is then transported up-river to Queenston, to be stored in piles on shore (Figure 1), or shipped to Hamilton for sand and gravel production. Consequently, there was concern over (i) the quality of the dredged material and therefore its subsequent use; and (ii) the potential for resuspension of contaminants during dredging operations and their subsequent impact on other water uses.

3.0 STUDY OBJECTIVES

The objectives of this study were to:

- i) determine the concentration and distribution of contaminants in bottom sediments of the Sir Adam Beck Power Reservoir.
- ii) determine the quality of commercially dredged material from the Niagara River Bar.
- iii) compare the data to available guidelines and to sediments from nearby areas.
- iv) evaluate the need for additional investigations.

4.0 MATERIALS AND METHODS

4.1 Field Sampling

Sampling of the Sir Adam Beck Power Reservoir and dredged material from the Niagara Bar (referred to as "dredgeate" in this report) occurred on November 15, 1983. The reservoir was formed by a dyke on land consisting of bedrock (Lockport dolomite) overlain with a variable overburden of silt and clay. Additional clay was added to this to provide water-tightness (H-EPCO, 1961). Unfortunately, because of the presence of the clay liner, cores could not be taken in the reservoir and subsequent radiodating was not attempted. However, at seven locations distributed within the reservoir, the top 3 cm of one or more Ekman dredge grabs were composited (Figure 1). Subsamples of this composite were placed in wide-mouth, solvent-rinsed amber glass jars with foil-lined caps for PCB/organochlorine pesticides and solvent extractables analyses. Clear glass jars with pulp-lined caps were used for metals, particle size, loss on ignition and nutrient analyses. Samples were kept refrigerated until analysed. Sampling locations were visually sighted from known reference points.

Three samples of dredgeate from the Niagara Bar region were obtained directly from the Queenston dredge pile by scooping up material with the appropriate jars at three randomly chosen locations.

Samples of surficial bottom sediments (top 3 cm) were also collected at twenty-six stations in the lower Niagara River and ten on the Niagara Bar (Figure 1)*. This was part of a larger survey (during August, 1983) encompassing the whole Niagara River, which was designed to determine the distribution and abundance of benthic macroinvertebrates and their relationship to sediment physical and chemical factors. Detailed methods and results will be reported in a subsequent Ministry report.

Data on the 1983 lower Niagara River and Niagara Bar sediment samples are included in this report for comparison to the reservoir and dredged material results.

* Lower Niagara River sampling stations are shown in Figure 2.

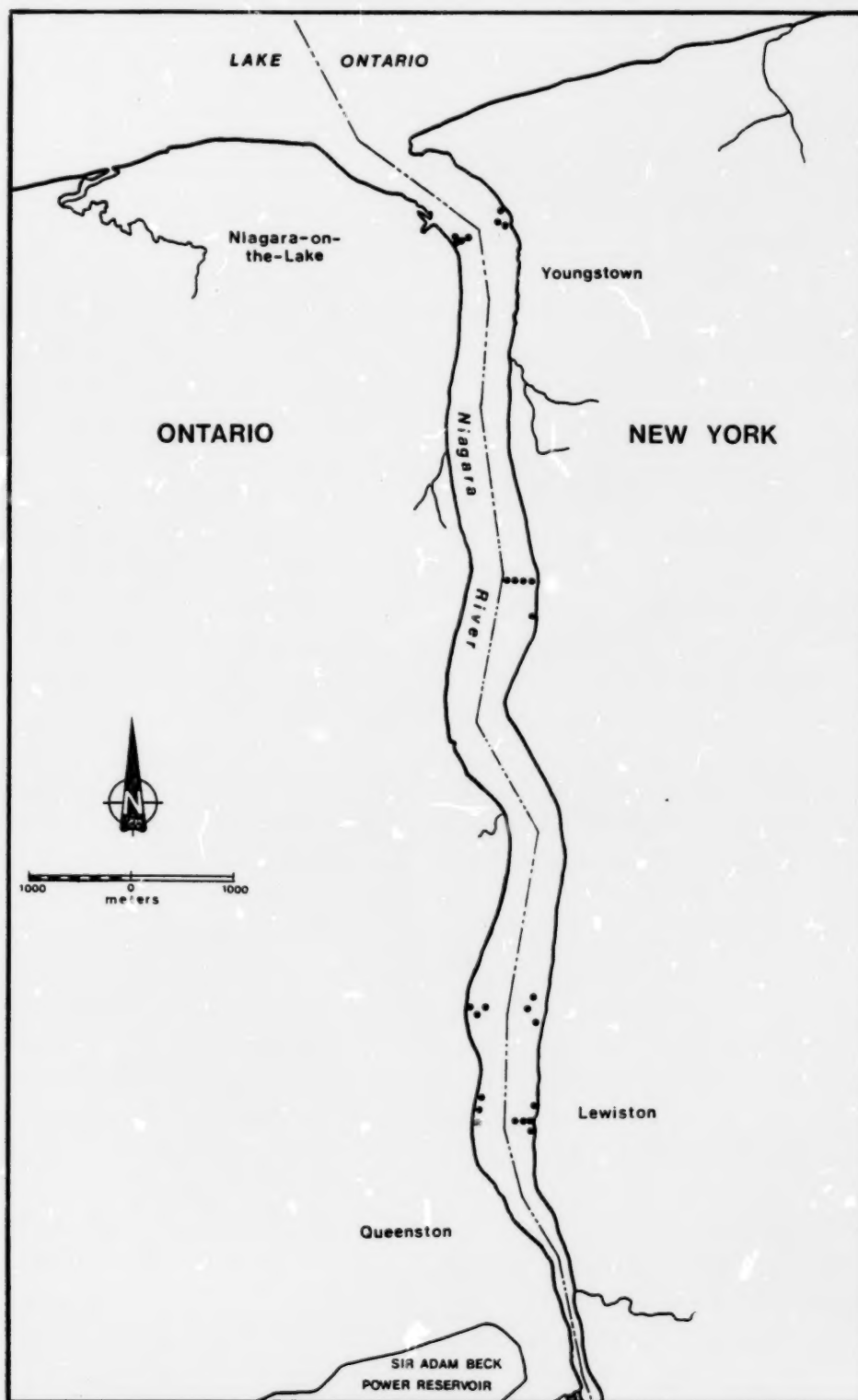


FIGURE 2 LOWER NIAGARA RIVER SEDIMENT SAMPLING STATIONS

4.2 Laboratory Analysis

All analyses were conducted at the Ministry of the Environment's main laboratory in Rexdale, Ontario according to the methods outlined in the "Handbook of Analytical Methods for Environmental Samples" (MOE, 1983). However, a brief outline of the analytical techniques used is provided below.

Particle size distribution was obtained through a combination of dry sieving and measurement of the angular distribution of scattered light in the sub-1000 um diameter fraction using a laser particle size analyzer.

Percent loss on ignition was determined gravimetrically after ignition at 475°C for one hour.

Total Phosphorus levels were determined by conversion to inorganic phosphorus using a sulphuric acid and potassium persulphate digestion, followed by neutralization and treatment to remove heavy metal interference. Phosphorus levels were then measured colourimetrically.

Total Kjeldahl Nitrogen was determined after sample digestion using sulphuric acid, mercuric oxide and potassium persulphate, followed by colourimetric analysis.

Total Trace Metal analysis was performed using hydrochloric/nitric acid digestion and inductively-coupled plasma spectrophotometry.

Total mercury analysis was achieved by digestion with a potassium permanganate and aqua regia acid mixture and analysis by cold vapour flameless atomic absorption spectrophotometry.

Solvent extractables (oils and greases) were determined by extraction with chloroform, followed by solvent evaporation and weighing of the remaining residue.

Organochlorine pesticides and total PCBs were extracted from the sediment samples with acetone, backwashed with water to remove the acetone and then extracted from the water using methylene chloride. The extract was then passed through sodium sulphate prior to cleanup with Florisil (PR) 100/20 mesh (dry column). Extracts were then analyzed by Ni^{63} electron capture gas chromatography utilizing various columns for the three extract fractions.

All chemical concentrations are expressed on a dry weight basis.

5.0 RESULTS

This section includes data obtained during sampling of the Sir Adam Beck reservoir and the Niagara Bar dredge pile at Queenston. Since surficial sediment sampling also occurred in the vicinity of the permitted dredging area in 1983, individual station data from this study are also included here to permit ready comparison with the dredgeate results. However, data on 1983 surficial sediment samples from the lower Niagara River are included in a summary fashion only, in the following Discussion section (6.1).

5.1 Sediment Physical Characteristics

Details on particle size distribution, nutrients, loss on ignition and solvent extractables content of sediments from the Sir Adam Beck reservoir and Niagara River Bar are presented in Table 1.

Overall, reservoir samples were dominated by fine-grained material (<62 μm diameter), averaging 57% silt and 32% clay. However, spatially, there was a marked increase in the proportion (from 2% to 32%) of sand (62 to 1000 μm diameter) towards the western portion (stations 5 to 7) of the reservoir. This was accompanied by a concomitant decrease in silt (from 66% to 37%). In contrast, Niagara Bar dredgeate and sediment samples were composed of much coarser material, averaging 93% and 88% sand, respectively. The relative proportion of fine-grained material in sediments can have a strong influence on bulk sediment chemistry, since smaller particles have larger adsorptive surfaces for contaminants (Förstner and Whittmann, 1983).

TABLE 1: PHYSICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR AND NIAGARA RIVER BAR.

Station	% Sand	% Silt	% Clay	Total Phosphorus mg/g	Total Kjeldahi Nitrogen mg/g	Loss on Ignition %	Solvent Extractables µg/g
<u>Sir Adam Beck Reservoir Sediment</u>							
1	2.4	65.9	31.7	0.6	1.5	4.4	920
2	4.7	63.6	31.7	0.7	1.8	4.7	1030
3	5.7	67.4	26.9	0.9	2.0	4.5	1030
4	4.6	64.9	30.5	0.7	1.8	4.5	1050
5	11.6	59.4	29.0	0.7	1.2	4.3	760
6	14.1	40.6	45.3	0.9	0.7	3.4	290
7	32.0	37.3	30.7	1.1	0.6	3.7	620
<u>Niagara Bar Dredgeate</u>							
1	88.7	9.1	2.2	0.4	0.3	0.4	510
2	90.3	7.4	2.3	0.3	<0.1 T	0.3	450
3	93.3	5.2	1.4	0.2	<0.1 T	0.5	430
<u>Niagara Bar Sediment</u>							
2374	81.7	15.6	2.7	0.5	0.3	0.9	40
2375	86.0	11.6	2.4	0.3	0.3	0.7	<10
2376	91.7	7.1	1.2	0.4	0.2	0.5	<10
2377	60.7	30.9	8.4	0.5	0.8	1.9	290
2378	90.6	9.2	0.2	0.4	0.2	0.6	50
2379	89.6	7.4	1.0	0.4	<0.1 T	0.5	<10
2380	80.4	15.2	4.4	0.5	0.2	0.7	<10
2381	86.9	11.1	2.0	0.4	0.2	0.6	170
2382	83.0	15.8	1.2	0.5	0.3	0.7	<10
2383	93.0	4.3	2.7	0.3	<0.1 T	0.4	40

5.2 Nutrients

Concentrations of total phosphorus in reservoir sediments ranged from 0.6 to 1.1 mg/g, whereas levels in Niagara Bar dredgeate and sediments were somewhat lower and more uniform, ranging from 0.2 to 0.4 mg/g and 0.3 to 0.5 mg/g, respectively (Table 1).

Total Kjeldahl nitrogen concentrations were generally higher in reservoir sediments (range: 0.6 to 2.0 mg/g) than in Niagara Bar dredgeate (<0.1 to 0.3 mg/g) and sediment (<0.1 to 0.8 mg/g).

Percent loss on ignition (LOI), a measure of organic, water and inorganic salts content, was again higher in reservoir sediments (3.4 to 4.7%) than in Niagara Bar dredgeate (0.3 to 0.5%) and sediment (0.4 to 1.9%).

Concentrations of total Kjeldahl nitrogen and percent LOI exhibited a trend towards lower levels in samples from the western end of the reservoir (stations 5 to 7).

5.3 Inorganics

Analytical results for the fourteen inorganics analyzed for in sediment samples are listed in Table 2.

With the exception of mercury, concentrations of inorganics were generally highest in the Sir Adam Beck reservoir sediments, lowest in Niagara Bar dredgeate and intermediate in Niagara Bar surficial sediments. This is evident from a comparison of the maximum concentrations observed in sediments from the reservoir, Niagara Bar dredgeate and Niagara Bar sediments. Respectively, these were: 21,000, 2,900 and 7,900 µg/g for aluminum; 13.23, 2.76 and 9.81 µg/g for arsenic; 68.0, 7.3 and 40.0 µg/g for barium; 1.70, 0.22, and 0.90 µg/g for cadmium; 11.0, 2.20 and 4.80 µg/g for cobalt; 36.0, 6.4 and 21.0 µg/g for chromium; 32.0, 6.6 and 12.0 µg/g for copper; 40,000, 6,700 and 20,000 µg/g for iron; 0.12, 0.03 and 0.22 µg/g for mercury; 46.0, 4.5 and 14.0 µg/g for nickel; 70.0, 8.4 and 21.0 µg/g for lead; 1.15, 0.14 and 0.96 µg/g for selenium; 1.8, <1.0 and <1.0 µg/g for silver; and 140.0, 27.0 and 150.0 µg/g for zinc.

TABLE 2: CONCENTRATIONS OF INORGANICS ($\mu\text{g/g}$) IN SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR AND NIAGARA BAR

Parameter	Sir Adam Beck Reservoir Sediment							Niagara Bar Dredgeate		
	1	2	3	4	5	6	7	1	2	3
Aluminum	17,000	17,000	15,000	15,000	15,000	21,000	17,000	2,200	2,000	2,900
Arsenic	10.00	9.70	9.03	8.65	6.43	9.41	13.23	2.76	2.20	1.20
Barium	56.0	57.0	50.0	49.0	54.0	68.0	67.0	6.0	4.7	7.3
Cadmium	1.60	1.60	1.60	1.70	0.90	0.84	1.30	0.22	<0.15	<0.15
Cobalt	9.6	9.6	9.2	9.3	8.0	11.0	10.0	2.20	1.60	2.20
Chromium	36.0	34.0	36.0	36.0	24.0	28.0	30.0	4.5	4.5	6.4
Copper	30.0	32.0	28.0	28.0	13.0	10.0	6.9	<1.0	1.6	6.6
Iron	23,000	23,000	22,000	22,000	22,000	32,000	40,000	5,000	5,000	6,700
Mercury	0.11	0.11	0.12	0.12	0.06	0.06	0.05	0.01	<0.01	0.03
Nickel	41.0	38.0	44.0	46.0	22.0	17.0	14.0	3.7	3.0	4.5
Lead	70.0	65.00	59.0	56.0	40.0	50.0	59.0	6.3	6.2	8.4
Selenium	0.73	0.67	1.15	0.88	0.25	0.30	0.41	0.09	0.14	0.09
Silver	1.8	1.2	<1.0	1.8	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc	130.0	130.0	140.0	140.0	90.0	79.0	74.0	20.0	23.0	27.0

TABLE 2 (Cont'd)

Parameter	Niagara Bar Sediment												
	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383			
Aluminum	7,900	3,800	4,800	5,900	4,500	3,400	3,600	3,700	5,800	2,600			
Arsenic	5.47	7.00	4.04	4.65	3.69	2.25	4.84	2.03	9.81	1.74			
Barium	30.0	22.0	34.0	31.0	21.0	14.0	38.0	17.0	40.0	15.0			
Cadmium	<0.20	0.25	<0.20	0.40	<0.20	0.25	0.90	0.20	0.20	<0.20			
Cobalt	4.80	4.70	3.00	4.60	2.60	2.40	2.90	2.60	5.40	2.00			
Chromium	16.0	11.0	16.0	18.0	21.0	9.0	13.0	13.0	16.0	5.2			
Copper	12.0	<5.0	4.6	10.0	5.5	<5.0	<5.0	5.0	12.0	<5.0			
Iron	16,000	12,000	18,000	14,000	13,000	10,500	13,000	14,000	20,000	7,200			
Mercury	0.19	0.18	0.13	0.22	0.09	0.08	0.15	0.12	0.20	0.13			
Nickel	13.0	9.8	8.4	14.0	7.2	5.8	7.4	6.2	14.0	4.7			
Lead	10.0	14.0	5.5	21.0	5.0	10.0	<3.0	11.0	<3.0	10.0			
Selenium	0.16	0.16	0.03	0.25	0.06	0.06	0.06	0.06	0.96	0.44			
Silver	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0			
Zinc	59.0	76.0	48.0	84.0	150.0	49.0	56.0	44.0	92.0	38.0			

Maximum concentrations of inorganics in the three Niagara Bar dredgeate samples were only 14% (mercury, selenium) to 55% (copper) of the maxima observed for surficial sediments from the Bar area, reflective of the predominance of sand in the former. Since the dredgeate and surficial samples are from the same area, it is probable that most of the fines were washed out of the dredgeate during the dredging operation.

The observed spatial trend towards higher sand and lower silt content in sediments from the western end of the reservoir tended to coincide with lower concentrations of copper, mercury, nickel, selenium, silver and zinc.

5.4 Solvent Extractables

Solvent extractables (oils and greases) concentrations exhibited considerable differences between the three groups of sediment samples. (Table 1). Again, reservoir samples contained the highest levels, with a range of 240 to 1,050 µg/g. However, contrary to the trend observed for most nutrients and inorganics, the Niagara Bar dredgeate (430 to 510 µg/g) had higher concentrations than the Bar sediment samples (<10 to 290 µg/g).

As noted previously for other parameters, solvent extractables also exhibited a tendency towards lower concentrations at the three stations in the western end of the reservoir which had a higher proportion of sand.

5.5 Organochlorines

Although sediments were analyzed for twenty-one organochlorine pesticides as well as total PCBs, only eight of these compounds were detected in one or more samples from each of the three groups of sediments (Table 3). Some of these, such as alpha-BHC, endrin and oxychlordan were only found in low concentrations in one or two samples.

PCBs were detected in three out of seven (43%) of the reservoir samples, with detected values ranging from 27 to 30 ng/g. This range was smaller than that observed in Niagara Bar sediments (30 to 80 ng/g).

**TABLE 3: CONCENTRATIONS OF PCBs AND ORGANOCHLORINE PESTICIDES (ng/g) IN
SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR AND NIAGARA BAR**

Parameter	Detection Limit	Sir Adam Beck Reservoir Sediment							Niagara Bar Dredgeate		
		1	2	3	4	5	6	7	1	2	3
Total PCBs	20	27	33	30	•	•	•	•	•	•	•
Aldrin	1.0	•	•	•	•	•	•	•	•	•	•
Dieldrin	2.0	•	•	•	•	•	•	•	•	•	•
α -BHC	1.0	•	•	•	1.0	•	•	•	•	•	•
β -BHC	1.0	•	•	•	•	•	•	•	•	•	•
γ -BHC	1.0	•	•	•	•	•	•	•	•	•	•
α -Chlordane	2.0	•	•	•	•	•	•	•	•	•	•
γ -Chlordane	2.0	•	•	•	•	•	•	•	•	•	•
p,p'-DDE	1.0	25	16	3	36	2	1	2	•	•	•
o,p'-DDT	5.0	•	•	•	•	•	•	•	•	•	•
p,p'-DDD	5.0	50	50	50	30	10	5	•	•	•	•
p,p'-DDT	5.0	10	15	12	10	5	•	•	•	•	•
DMDT (Methoxychlor)	5.0	•	•	•	•	•	•	•	•	•	•
α -Endosulfan	2.0	•	•	•	•	•	•	•	•	•	•
β -Endosulfan	4.0	•	•	•	•	•	•	•	•	•	•
Endosulfan sulfate	4.0	•	•	•	•	•	•	•	•	•	•
Endrin	4.0	•	•	•	•	•	•	•	•	•	•
Hexachlorobenzene	1.0	•	•	•	•	•	•	•	•	•	2.0
Heptachlor	1.0	•	•	•	•	•	•	•	•	•	•
Heptachlor epoxide	1.0	•	•	•	•	•	•	•	•	•	•
Mirex	5.0	•	•	•	•	•	•	•	•	•	•
Oxychlordane	2.0	•	•	•	•	•	•	•	•	•	•

• = not detected at analytical detection limit indicated.

TABLE 3 (Cont'd)

Parameter	Niagara Bar Sediment									
	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383
Total PCBs	30	60	•	50	•	75	•	80	•	•
Aldrin	•	•	•	•	•	•	•	•	•	•
Dieldrin	18	15	15	26	3	6	4	13	10	12
α -BHC	•	•	•	•	•	•	•	•	•	•
β -BHC	•	•	•	•	•	•	•	•	•	•
γ -BHC	•	•	•	•	•	•	•	•	•	•
α -Chlordane	•	•	•	•	•	•	•	•	•	•
γ -Chlordane	•	•	•	•	•	•	•	•	•	•
p,p'-DDE	1	3	1	2	•	2	•	2	•	•
o,p'-DDT	•	•	•	•	•	•	•	•	•	•
p,p'-DDD	•	•	•	•	•	•	•	•	•	•
p,p'-DDT	•	•	•	•	•	•	•	•	•	•
DMDT (Methoxychlor)	•	•	•	•	•	•	•	•	•	•
α -Endosulfan	•	•	•	•	•	•	•	•	•	•
β -Endosulfan	•	•	•	•	•	•	•	•	•	•
Endosulfan sulfate	•	•	•	•	•	•	•	•	•	•
Endrin	•	•	•	•	•	•	•	•	36	•
Hexachlorobenzene	8	13	2	9	3	7	2	12	3	4
Heptachlor	•	•	•	•	•	•	•	•	•	•
Heptachlor epoxide	•	•	•	•	•	•	•	•	•	•
Mirex	•	•	•	•	•	•	•	•	•	•
Oxychlordane	•	•	2	•	•	•	2	•	•	•

• = not detected at analytical detection limit indicated.

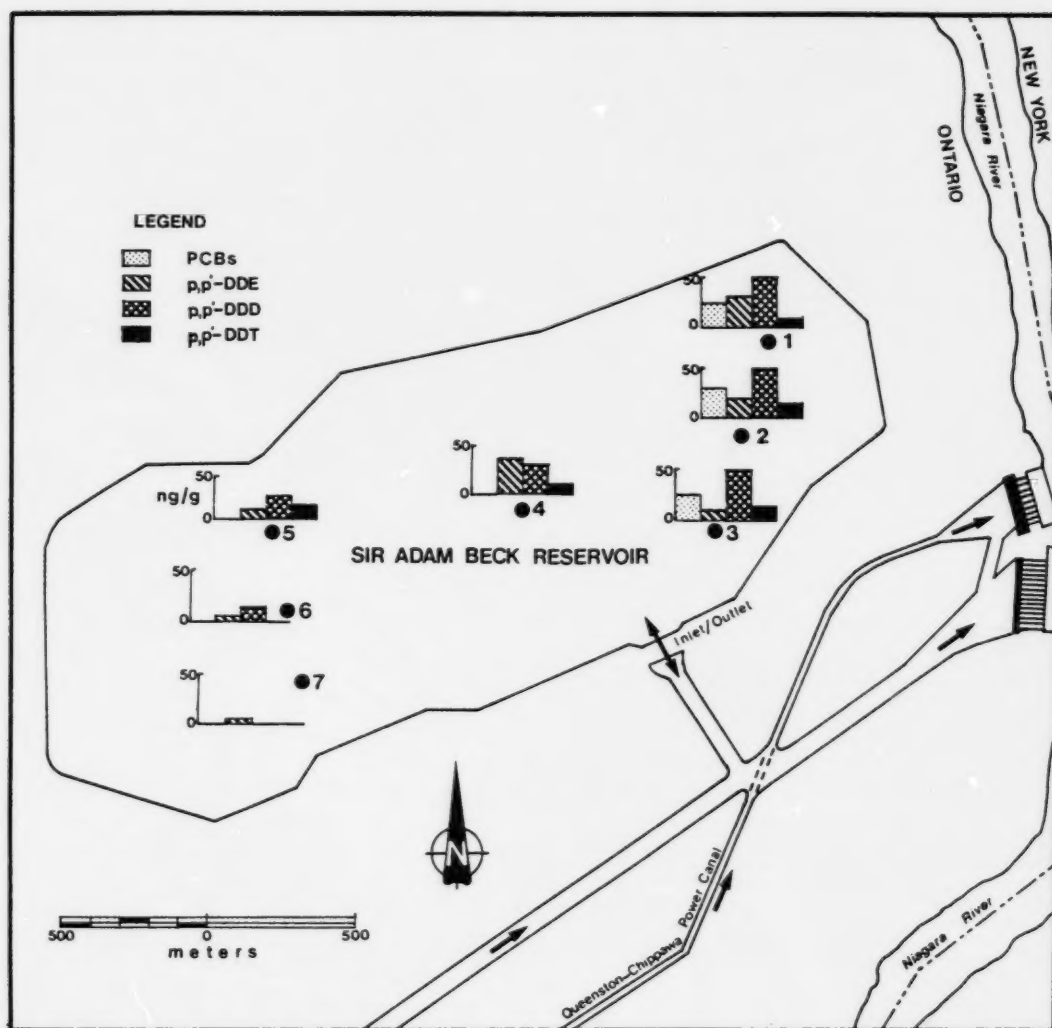


FIGURE 3 SPATIAL DISTRIBUTION OF TOTAL PCBs AND DDT ISOMERS AND METABOLITES (ng/g) IN SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR

Reservoir sediments did not contain detectable concentrations of dieldrin or hexachlorobenzene, organochlorines which were ubiquitous in Niagara Bar sediment samples (Table 3).

The DDT metabolite p,p'-DDE was detected in 60% of bottom sediment samples from the Niagara Bar at levels (1 to 3 ng/g) close to the method detection limit. In contrast, p,p'-DDE as well as another metabolite, p,p'-DDD and the parent compound p,p'-DDT were found in 85% to 100% of the reservoir sediment samples, reaching concentrations considerably above the method detection limit. The range of reservoir concentrations were: p,p'-DDE- 1 to 36 ng/g; p,p'-DDD- 5 to 50 ng/g; p,p'-DDT- 5 to 15 ng/g.

Concentrations of total PCBs and DDT compounds also had a spatial distribution pattern in reservoir sediments (Figure 3) similar to that noted previously for nutrients, certain inorganics and solvent extractables.

Dredgeate from the Niagara Bar was essentially free of organochlorine contaminants, with only one sample containing hexachlorobenzene at a low concentration (2 ng/g).

6.0 DISCUSSION

6.1 Sir Adam Beck Power Reservoir

Evaluation of Contaminant Concentrations:

Comparison of data in Tables 1 and 2 with dredged material disposal guidelines in Table 4 shows that a number of reservoir surficial sediment samples contained concentrations of arsenic, cadmium, chromium, copper, iron, nickel, lead, silver and zinc which were above the current Ministry of the Environment guidelines for the safe open water disposal of dredgeate. However, the open water disposal guidelines are not really applicable to this situation, since: i) the reservoir has not required dredging since its construction in 1954 (J.C. Sands, Ontario Hydro, personal communication), and ii) should dredging become necessary, the material is more likely to be disposed of on land and would therefore need to be evaluated on that basis. Accordingly, reference to the proposed MOE guidelines on the suitability of dredged

TABLE 4: ONTARIO DREDGED MATERIAL CLASSIFICATION GUIDELINES
(µg/g unless otherwise specified)

Parameter	Open Water* Disposal	Unrestricted** Land Use	Restricted*** Land Use
<u>1A)</u> Cadmium	1.0	1.6	4.0
Lead	50.0	60.0	500.0
Mercury	0.3	0.5	0.5
PCBs	0.05	2.0	2.0
<u>1B)</u> Loss on Ignition	6.0%	-	-
Oil and Grease	1,500	-	-
Total Phosphorus	1,000	-	-
Total Kjeldahl Nitrogen	2,000	-	-
<u>2)</u> Arsenic	8.0	14.0	20.0
Cobalt	50.0	20.0	25.0
Copper	25.0	100.0	100.0
Chromium	25.0	120.0	120.0
Iron	10,000.0	35,000.0	35,000.0
Nickel	25.0	32.0	60.0
Silver	0.5	-	-
Selenium	-	1.6	2.0
Zinc	100.0	220.0	500.0

Source of guidelines: MOE (1986), draft report; Persaud and Wilkins (1976).

Explanation of Classifications [see MOE (1986) for additional details]:

- * dredged material with concentrations below these maxima may be disposed in open water if the site is on the Great Lakes or their interconnecting waterways subject to the Open Water Site Selection guidelines.
- ** dredged material with individual sample concentrations below the group 1A maxima and average concentrations per stratum below the group 2 maxima may be placed on any lands with the owner's approval or at an engineered, confined in-water location; proper stabilization of material is required.
- *** dredged material with individual sample concentrations below group 1A maxima and average concentrations per stratum below the group 2 maxima may be used on lands currently zoned either commercial, industrial or parkland or at an engineered, confined in-water location; proper stabilization of material is required.

material for land disposal (Table 4) shows that the concentrations of cadmium (in one out of seven samples) and lead (in two samples) were above the maximum levels permitted for unrestricted land use of dredged material and would necessitate restricted land disposal*.

Contaminant and Particle Size Correlations:

Although mean concentrations of aluminum, arsenic, cadmium, nickel, lead, selenium, p,p'-DDT, p,p'-DDD, p,p'-DDE and solvent extractables were from two-to-seven-fold higher in reservoir sediments than in material from the lower Niagara River, only levels of DDT and its metabolites were in fact significantly higher when the 95% confidence intervals of the means were also considered (Table 5). Furthermore, it is important to note that fine-grained material in the less than 62 μm diameter size class constituted a much higher percentage of the reservoir samples (85%) than of the lower Niagara River sediments (26%). Grain size has an important influence on the concentration of contaminants such as metals in sediments, since a large proportion of the fluvial transport of matter occurs in the form of suspended material with mean grain sizes of 2 to 63 μm diameter (Förstner and Whittmann, 1983). Smaller particles have a larger surface area-to-weight ratio than larger diameter particles and therefore can potentially adsorb more contaminants. Consequently, the lower Niagara River sediment samples, with their lower proportion of silts and clays and concomitantly lower surface area, would be expected to contain lower concentrations of adsorbed contaminants than would samples with a higher proportion of very fine material.

Therefore, the relationships between selected inorganic and organic contaminants** and the percent <62 μm (silt + clay), percent <14 μm (fine silt + clay) and percent <4 μm diameter (clay) particle size classes in the reservoir and lower Niagara River samples were tested using a Pearson correlation matrix and transformed*** data. However, it must be stressed that these correlations are approximate, since they are based on sediment chemistry on bulk samples and not on analyses

* See footnote, Table 4, for definition.

** Those with quantified levels in all or most samples of both data sets.

*** See footnote, Table 5 for details.

TABLE 5: SUMMARY OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS FROM THE SIR ADAM BECK POWER RESERVOIR, NIAGARA BAR AND LOWER NIAGARA RIVER

Parameter	Sir Adam Beck Reservoir		Niagara Bar		Lower Niagara River
	Bottom Sediment	Dredgeate	Bottom Sediment	Bottom Sediment	Bottom Sediment
Aluminum, µg/g	16,606 (12,351-22,326)	2,337 (1,018-5,363)	4,382 (782-24,544)	6,788 (1,356-18,773)	
Arsenic, µg/g	9.3 (5.5-15)	2.0 (0.02-7.7)	4.1 (1.9-14)	3.0 (0.9-7.0)	
Barium, µg/g	57 (41-76)	7.9 (2.1-15)	25 (11-58)	35 (8.2-135)	
Cadmium, µg/g	1.33 (0.58-2.46)	0.12 (-0.18-0.53)	0.24 (-0.15-0.82)	0.34 (-0.75-6.3)	
Cobalt, µg/g	9.5 (7.5-12)	2.0 (0.79-4.0)	3.4 (1.4-7.0)	4.7 (1.6-12)	
Chromium, µg/g	31 (21-46)	5.1 (1.9-12)	13 (5.1-31)	27 (12-55)	
Copper, µg/g	18 (4-80)	2.1 (-0.9-10)	5.0 (0.7-21)	12 (3.3-40)	
Iron, µg/g	25,602 (14,289-45,872)	5,512 (2,663-11,409)	13,299 (6,948-25,457)	19,343 (10,019-37,344)	
Mercury, µg/g	0.09 (0.01-0.17)	0.01 (-0.04-0.07)	0.15 (0.05-0.26)	0.22 (-0.07-0.59)	
Nickel, µg/g	29 (8.3-95)	3.7 (1.4-8.3)	8.5 (3.4-20)	14 (5.6-33)	
Lead, µg/g	56 (36-88)	8.9 (3.1-14)	7.1 (-0.3-90)	21 (8.5-50)	
Selenium, µg/g	0.60 (0.98-2.6)	0.10 (-0.01-0.23)	0.13 (-0.11-0.43)	0.16 (-0.57-2.11)	
Silver, µg/g	0.89 (-0.09-3.0)	<1.0	<1.0	0.60 (0.22-1.1)	
Zinc, µg/g	109 (55-216)	23 (12-44)	64 (26-163)	98 (50-196)	
PCBs, ng/g	16 (3-65)	<20	24 (2-191)	65 (5-691)	
Dieldrin, ng/g	<2	<2	10 (2-44)	10 (1-76)	
α-BHC, ng/g	0.6 (0.2-2)	<1	<1	0.7 (-0.2-3)	
p,p'-DDT, ng/g	7 (0.7-36)	<5	<5	<5	
p,p'-DDD, ng/g	18 (0.2-302)	<5	<5	<5	
p,p'-DDE, ng/g	6 (-0.6-136)	<1	1 (0.6-2)	0.9 (-0.4-3)	
α-Endosulfan, ng/g	<2	<2	<2	3 (-0.7-44)	
Endrin, ng/g	<4	<4	3 (-0.3-20)	2 (0.3-7)	
Hexachlorobenzene, ng/g	<1	0.9 (-0.7-10)	5 (2-23)	9 (0.3-80)	
Mirex, ng/g	<5	<5	<5	3 (0.03-17)	
Oxychlorodane, ng/g	<2	<2	1 (0.5-2)	<2	
Solvent Extractables, µg/g	755 (242-2,351)	462 (316-675)	21 (0.7-699)	130 (7.1-2,128)	

TABLE 5 (cont'd)

Parameter	Sir Adam Beck Reservoir	Niagara Bar		Lower Niagara River
	Bottom Sediment	Dredgeate	Bottom Sediment	Bottom Sediment
Total Phosphorus, mg/g	0.8 (0.4-1.2)	0.3 (-0.07-0.8)	0.4 (0.3-1.6)	0.5 (0.3-0.8)
Total Kjeldahl Nitrogen, mg/g	1.3 (0.2-3.3)	0.1 (-0.03-0.9)	0.2 (-0.1-0.8)	0.4 (-0.1-1.0)
% Loss on Ignition	4.2 (3.1-5.5)	0.4 (0.1-0.9)	0.7 (0.1-1.7)	1.1 (0.29-2.4)
% <62 μm	85.0 (50.5-100)	5.5 (1.7-11.2)	18.5 (12.2-89.9)	26.1 (1.2-67.5)
% <14 μm	52.0 (32.4-71.3)	3.3 (0.7-7.8)	4.9 (0.0008-18.5)	15.5 (0.04-50.3)
% <4 μm	26.6 (15.3-39.7)	1.6 (0.4-3.6)	1.5 (0.001-6.2)	6.4 (0.001-24.1)
Number of Samples	7	3	10	26

NOTE: (1) Concentrations are geometric means and 95% confidence intervals (in brackets) derived using the transformation $Z = \ln(x+1)$; percentages and their 95% confidence intervals were derived using the transformation $Z = \arcsin\sqrt{x}$.

(2) Only those organochlorines detected in one or more data sets (see Table 3) are summarized here.

performed on each of the above size fractions. Nevertheless, comparison of Tables 6 and 7 indicates some significant ($p < 0.05$) differences in the parameter correlations for the two sample groups.

Reservoir sediments exhibited significant ($p < 0.05$) positive correlations among cadmium, chromium, copper, mercury, nickel, lead, selenium and zinc levels and between some of these and % LOI, total Kjeldahl nitrogen and solvent extractables concentrations (Table 6). Such correlations among contaminants are indicative of a common point source: namely, the waters diverted for hydro-electric purposes which may receive contaminants from upstream sources. It is noteworthy that previous (1981-1982) Ministry monitoring (NRTC, 1984) found that certain upstream Ontario municipal and industrial dischargers to the Chippawa Channel, Welland River or Queenston-Chippawa Power Canal exceeded arbitrary loading levels set for chromium, copper, iron, nickel, lead and zinc. Monitoring by MOE in 1982 also detected elevated mean concentrations of copper and chromium in Ontario waters of the lower Chippawa Channel, as well as elevated levels of chromium, lead, nickel, selenium and zinc in Cladophora collected in this area (NRTC, 1984). These occurrences may be related to nearby tributary inputs, since a 1983 MOE survey detected, at the mouths of some Ontario tributaries to the upper Niagara River: elevated concentrations of cadmium, chromium, lead, mercury, nickel and selenium in suspended particulates; concentrations of copper and zinc above the Provincial Water Quality Objectives in water samples; and bottom sediment concentrations of chromium, mercury, nickel, lead and zinc above the MOE guidelines for safe open water disposal of dredgeate (Hart, 1986).

The strong positive correlation of inorganics with % LOI and solvent extractables is probably due to the fact that, in addition to particle size and surface area, sediment organic content has an important influence on the partitioning of contaminants onto particulate matter (Förstner and Whittmann, 1983). However, fewer of the sediment contaminants were strongly associated with particle size. These were: copper, mercury, nickel, zinc and % LOI with % $< 62 \mu\text{m}$; and aluminum and cobalt with % $< 4 \mu\text{m}$. The correlation of aluminum with the % $< 4 \mu\text{m}$ is due to the fact that this element is a major constituent of clay minerals (Förstner and Whittmann, 1983). However, the poor correlation of many of the above-noted contaminants to this or other size fractions

TABLE 6: CORRELATION MATRIX OF INTERRELATIONSHIPS BETWEEN VARIABLES IN BOTTOM SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR

	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	Σ LOI	TP	TMN	Sol.Ext.	PCBs	Σ <62	Σ <14	Σ <4
Al	1.00000																				
As	.39445	1.00000																			
Ba	.84112	.56255	1.00000																		
Cd	-.47950	.31646	-.57058	1.00000																	
Co	.84925	.69753	.68241	-.05499	1.00000																
Cr	-.20557	.38923	-.44174	.92723	.23577	1.00000															
Cu	-.42182	-.25983	-.76409	.75157	-.25302	.73983	1.00000														
Fe	.60163	.72320	.88844	-.39123	.63848	-.31105	-.84374	1.00000													
Hg	-.43804	-.11487	-.77154	.84457	-.14048	.85383	.96220	-.73966	1.00000												
Ni	-.52674	-.27403	-.85167	.78378	-.29953	.78755	.97959	-.84707	.98156	1.00000											
Pb	.09133	.67925	-.02912	.79438	.42886	.86158	.51307	.00389	.58420	.46903	1.00000										
Se	-.48246	.11228	-.69480	.88076	-.05821	.90913	.78697	-.51441	.91338	.85366	.62823	1.00000									
Zn	-.52665	-.21639	-.83514	.82024	-.27372	.79906	.97853	-.81600	.98985	.99663	.51249	.88035	1.00000								
Σ LOI	-.74316	-.36102	-.85369	.71195	-.62643	.51898	.87041	-.85219	.80143	.86457	.30999	.65703	.87012	1.00000							
TP	.28830	.56618	.56306	-.27173	.42987	-.21118	-.71642	-.80765	-.54408	-.66081	-.10428	-.18987	-.61432	-.66138	1.00000						
TMN	-.63202	-.38913	-.89864	.71600	-.45215	.64417	.95114	-.89705	.93026	.96499	.33112	.80863	.96473	.92913	-.61608	1.00000					
Sol. Ext.	-.83956	-.15099	-.81828	.81520	-.61392	.58372	.75483	-.68335	.74549	.78800	.39526	.70792	.80507	.94412	-.47855	.83480	1.00000				
PCBs	-.14151	.10673	-.33743	.61514	-.03114	.63284	.74235	-.47656	.68834	.65464	.68381	.44227	.68553	.63416	-.34000	.66915	.55362	1.00000			
Σ <62	-.18844	-.37536	-.64359	.52415	-.14292	.60218	.93858	-.83719	.86208	.89550	.40057	.61581	.87395	.70429	-.81010	.83539	.51382	.66528	1.00000		
Σ <14	.69850	-.10632	.21112	-.17868	.55676	.12596	.25437	-.13277	.18611	.15319	.15740	-.03254	.12697	-.18523	-.33374	.04316	-.43416	.23059	.53089	1.00000	
Σ <4	.92559	.15507	.73183	-.63232	.75595	-.34370	-.46167	.52498	-.48110	-.54480	-.19103	-.53721	-.56139	-.80053	.26926	-.63286	-.92508	-.37696	-.21356	.70517	1.00000

NOTE: Underlined values are significant at the 95% confidence level ($p \leq 0.05$ = 0.754; 5 d.f.).

TABLE 7: CORRELATION MATRIX OF INTERRELATIONSHIPS BETWEEN VARIABLES IN BOTTOM SEDIMENTS OF THE LOWER NIAGARA RIVER

	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn	% LOI	TP	TKM	Sol. Ext.	PCBs	% <62	% <14	% <4
Al	1.00000																				
As	<u>.89638</u>	1.00000																			
Ba	<u>.78112</u>	<u>.73147</u>	1.00000																		
Cd	<u>.89987</u>	<u>.87754</u>	<u>.52623</u>	1.00000																	
Co	<u>.97663</u>	<u>.84661</u>	<u>.74700</u>	<u>.50472</u>	1.00000																
Cr	<u>.18180</u>	<u>.26567</u>	<u>.12398</u>	<u>.13815</u>	<u>.10195</u>	1.00000															
Cu	<u>.21791</u>	<u>.17018</u>	<u>.14348</u>	<u>.86321</u>	<u>.23565</u>	<u>.05851</u>	1.00000														
Fe	<u>.62039</u>	<u>.64524</u>	<u>.52616</u>	<u>.18211</u>	<u>.57283</u>	<u>.48377</u>	<u>-.03034</u>	1.00000													
Hg	<u>-.06513</u>	<u>-.07462</u>	<u>-.16669</u>	<u>-.15356</u>	<u>-.14078</u>	<u>.18029</u>	<u>-.07516</u>	<u>.12473</u>	1.00000												
Ni	<u>.94433</u>	<u>.82258</u>	<u>.82251</u>	<u>.51793</u>	<u>.92372</u>	<u>.16887</u>	<u>.19950</u>	<u>.48837</u>	<u>-.16968</u>	1.00000											
Pb	<u>-.58093</u>	<u>-.51516</u>	<u>-.49838</u>	<u>-.75405</u>	<u>-.52977</u>	<u>.00559</u>	<u>-.26979</u>	<u>-.23758</u>	<u>.01511</u>	<u>-.55349</u>	1.00000										
Se	<u>.21177</u>	<u>.03923</u>	<u>.20676</u>	<u>.25697</u>	<u>.19248</u>	<u>.12828</u>	<u>.14498</u>	<u>-.07369</u>	<u>.02900</u>	<u>.43383</u>	<u>-.13193</u>	1.00000									
Zn	<u>-.07262</u>	<u>.10447</u>	<u>.38046</u>	<u>.22402</u>	<u>-.16532</u>	<u>.80297</u>	<u>-.12935</u>	<u>.24896</u>	<u>.15070</u>	<u>-.00620</u>	<u>-.15000</u>	<u>.05181</u>	1.00000								
% LOI	<u>.61376</u>	<u>.48743</u>	<u>.42832</u>	<u>.91380</u>	<u>.61558</u>	<u>.16289</u>	<u>.33363</u>	<u>.19530</u>	<u>-.00074</u>	<u>.72658</u>	<u>-.28927</u>	<u>.77595</u>	<u>-.15331</u>	1.00000							
TP	<u>.47145</u>	<u>.36057</u>	<u>.30137</u>	<u>.20657</u>	<u>.44289</u>	<u>.53933</u>	<u>.28386</u>	<u>.46924</u>	<u>-.26715</u>	<u>.48294</u>	<u>-.03613</u>	<u>.37830</u>	<u>-.09156</u>	<u>.50527</u>	1.00000						
TKM	<u>.61332</u>	<u>.41353</u>	<u>.51892</u>	<u>.42121</u>	<u>.62338</u>	<u>.03979</u>	<u>.34289</u>	<u>.12847</u>	<u>-.13424</u>	<u>.74294</u>	<u>-.31864</u>	<u>.73736</u>	<u>-.09825</u>	<u>.91939</u>	<u>.45566</u>	1.00000					
Sol. Ext.	<u>.38814</u>	<u>.16319</u>	<u>.35840</u>	<u>.38800</u>	<u>.44814</u>	<u>-.21550</u>	<u>.27812</u>	<u>-.19619</u>	<u>-.10711</u>	<u>.45695</u>	<u>-.32558</u>	<u>.39304</u>	<u>-.15827</u>	<u>.53776</u>	<u>.06190</u>	<u>.61827</u>	1.00000				
PCBs	<u>-.30233</u>	<u>-.35939</u>	<u>-.06474</u>	<u>.14757</u>	<u>-.28626</u>	<u>-.14346</u>	<u>.05161</u>	<u>-.15119</u>	<u>-.03488</u>	<u>-.16485</u>	<u>-.04745</u>	<u>.38498</u>	<u>.24522</u>	<u>.02034</u>	<u>-.03318</u>	<u>.05792</u>	<u>.16564</u>	1.00000			
% <62	<u>.83608</u>	<u>.69312</u>	<u>.61905</u>	<u>.55842</u>	<u>.85165</u>	<u>.00779</u>	<u>.31805</u>	<u>.36622</u>	<u>-.10685</u>	<u>.86808</u>	<u>-.56868</u>	<u>.53240</u>	<u>-.20841</u>	<u>.82780</u>	<u>.39276</u>	<u>.79827</u>	<u>.55015</u>	<u>-.02486</u>	1.00000		
% <14	<u>.93519</u>	<u>.80520</u>	<u>.73518</u>	<u>.59881</u>	<u>.95137</u>	<u>.08468</u>	<u>.25013</u>	<u>.57278</u>	<u>-.11653</u>	<u>.88773</u>	<u>-.61068</u>	<u>.22035</u>	<u>-.11259</u>	<u>.63141</u>	<u>.33601</u>	<u>.63553</u>	<u>.44985</u>	<u>-.18062</u>	<u>.90706</u>	1.00000	
% <4	<u>.93881</u>	<u>.85531</u>	<u>.71914</u>	<u>.56405</u>	<u>.95015</u>	<u>.09431</u>	<u>.18667</u>	<u>.59320</u>	<u>-.10969</u>	<u>.88577</u>	<u>-.58387</u>	<u>.17777</u>	<u>-.13381</u>	<u>.59152</u>	<u>.32859</u>	<u>.58103</u>	<u>-.41201</u>	<u>-.21894</u>	<u>.87688</u>	<u>.99045</u>	1.00000

NOTE: Underlined values are significant at the 95% confidence level ($p \leq 0.05 = 0.388; 24 \text{ d.f.}$).

is perhaps related to the hydrological characteristics of the reservoir (see pg. 31). As a result, the sediments pumped into the reservoir along with the water, which are mainly "fines", are not subjected to the sorting processes typical of a riverine system.

The strong negative correlation of iron with most metals was unusual, considering the tendency of most metals to co-precipitate with ferric oxides (Mudroch, 1985). However, iron did exhibit a significant positive correlation with barium and total phosphorus concentrations (Table 6). For the latter, this may be related to the immediate upstream municipal input of phosphorus (Niagara Falls WPCP) to the Queenston-Chippawa Power Canal and to the higher molar adsorption coefficient of iron oxides for phosphorus than for metals (Lum and Gammon, 1985).

Significant positive correlations were also evident among many of the lower Niagara River sediment parameters. However, this group (ie. arsenic, barium, cadmium, cobalt, iron, nickel, % LOI, total phosphorus, total Kjeldahl nitrogen and solvent extractables) (Table 7) is somewhat different from the intercorrelated contaminants identified previously for the reservoir. The strong positive correlation between levels of the above contaminants with those of aluminum and the % <62 μm , % <14 μm or % <4 μm size fractions reflects the fluvial transport of fine-grained (clay) material with adsorbed contaminants derived from upstream sources. Mean concentrations of the above-noted lower river contaminants were therefore normalized to the mean percentage of <62 μm material in Sir Adam Beck reservoir sediments (85%) to provide a common basis for comparison of the two sediment data groups. After this procedure, only the mean concentrations of cadmium and selenium were still marginally (15% to 20%) higher in reservoir sediments than in the lower Niagara River (Table 8). Reservoir solvent extractables still remained about two-fold higher, but in view of the magnitude of the 95% confidence limits associated with these values (Table 5), are unlikely to have been significantly higher. Furthermore, as noted previously, this mathematical "correction" of bulk sediment chemistry can only be approximate, since chemical analyses were not performed on individual sediment size fractions. Nevertheless, the latter has been done for sediments from other locations, and Mudroch (1985) found that the highest concentrations of metals were indeed associated with various size fraction groups of <63 μm diameter.

TABLE 8: COMPARISON OF SELECTED CHEMICAL PARAMETERS IN BOTTOM SEDIMENTS OF THE SIR ADAM BECK POWER RESERVOIR AND THE LOWER NIAGARA RIVER AFTER GRAIN-SIZE CORRECTION

Parameter	Sir Adam Beck Reservoir	Lower* Niagara River
Aluminum, $\mu\text{g/g}$	16,606	22,106
Arsenic, $\mu\text{g/g}$	9.3	9.7
Barium, $\mu\text{g/g}$	57	114
Cadmium, $\mu\text{g/g}$	1.33	1.10
Cobalt, $\mu\text{g/g}$	9.5	15
Iron, $\mu\text{g/g}$	25,602	62,994
Nickel, $\mu\text{g/g}$	29	46
Selenium, $\mu\text{g/g}$	0.60	0.52
Solvent Extractables, $\mu\text{g/g}$	755	423
Total Phosphorus, mg/g	0.8	1.6
Total Kjeldahl Nitrogen, mg/g	1.3	1.3

* Mean lower Niagara River concentrations (Table 5) normalized to the same mean % <62 μm (85%) as Sir Adam Beck Reservoir sediments.

Significance of DDT:

DDT was widely used in Ontario (particularly in the Niagara peninsula fruitbelt) prior to 1970. However, due to its persistence and harmful effects in the environment, use of this pesticide has been prohibited since the beginning of 1970, except for a few specialized insect and rodent control applications. The insect control uses (cutworm control in tobacco and tarnished plant bug control in apples) were prohibited in 1972 and 1973, respectively. Since July 1974, DDT use has been restricted to the control of bats and mice by permit only (MOE, 1976; MOE, 1982). Amounts used for this purpose have been relatively small, and are unlikely to contribute losses to the environment, since the material is applied in enclosed spaces, such as attics. For example, during the period 1980 to 1983, the maximum amounts for which permits were held in the Niagara Region were about 16 kg (6 kg in 1981; 10 kg in 1983 - J. Miller, MOE, personal communication).

Although many years may be required for the breakdown of DDT in soils (Verschuere, 1983), its rate of degradation in aquatic sediments can be considerably more rapid. Muir and Yarechewski (1984) found that the half-life* of DDT in pond and lake sediments ranged from 86 to 134 days and was generally proportional to the temperature and redox potential of the sediments. Therefore, the rate of degradation of DDT on suspended materials or at the sediment-water interface would likely be slower than in subsurface or anoxic sediments.

Consequently, the detection of p,p'-DDT in addition to its metabolites p,p'-DDD and p,p'-DDE in reservoir sediments was unexpected and indicates ongoing inputs from upstream areas. Furthermore, these organochlorines were also found at elevated levels in caged clams stationed at the south shore of the reservoir, just east of the inlet/outlet (opposite station 3) in 1981. As in the reservoir sediments, p,p'-DDD was predominant in clam tissues, followed in decreasing order by p,p'-DDE and p,p'-DDT (NRTC, 1984). In contrast, fish (yellow perch) captured in the reservoir in 1982 contained p,p'-DDE and p,p'-DDD, but no p,p'-DDT (A. Johnson, MOE, personal communication). These fish were suitable for unrestricted consumption by humans (MOE/MNR, 1986). In view of the low aqueous solubility of these

* time required for 50% loss of original compound.

contaminants (Verschuere, 1983) it is probable that a proportion of their total loading to the reservoir was associated with fine particulate matter (Choi and Chen, 1976). Combined with a slower rate of degradation on suspended particulates, this may explain the detection of DDT in clam tissues but not in fish since the former are filter-feeders and would have a greater exposure to both aqueous and particulate-associated contaminants.

At present, it is difficult to say whether inputs of DDT and its metabolites to the reservoir are related to recent or past activities. For example, Frank et al. (1981) calculated an annual average loading of about 73 g/year for DDT and its metabolites from five Ontario tributaries to the upper Niagara River during the 1974 to 1977 period. This particulate-associated loading was largely ascribed to past agricultural uses of DDT in the tributaries' watersheds. Samples of water and suspended particulates collected by Environment Canada also indicated sources of DDT to the Chippawa Channel in 1981 (NRTC, 1984). DDT and its metabolites were also detected in municipal water pollution control plant and urban runoff samples collected in the Fort Erie, Welland and Niagara Falls, Ontario areas during 1981 and 1982 (NRTC, 1984). Finally, a 1983 MOE survey also detected DDT and its metabolites in suspended particulates and bottom sediments of some Ontario tributaries to the Chippawa Channel and Welland River (Hart, 1986). The above information suggests that past agricultural use and subsequent runoff may still account for the detection of DDT in tributary and urban runoff, although illegal use may also be implicated.

Present inputs or losses of DDT to the aquatic environment may also result from the use of the pesticide dicofol (Kelthane), which can be contaminated with DDT residues (Moore, 1984). Current formulations of this chemical contain about 2.5% DDT residues*, whereas older material (prior to January, 1985) probably contained between 5% and 6% (R. Larkin, Rohm and Haas, Philadelphia, personal communication). An estimated 2100 kg of this miticide were used in the Niagara Region during 1983 (W. McGee, Ontario Ministry of Agriculture and Food, personal communication). Unfortunately, the potential contribution of dicofol use to DDT detections cannot be substantiated at this time, since reservoir samples were not analyzed for this compound.

* DDT residues includes the o,p' and p,p' isomers of DDT, DDD, DDE and extra-chlorine DDT.

Spatial Distribution of Contaminants:

The tendency towards somewhat higher concentrations of certain contaminants (copper, mercury, nickel, selenium, silver, zinc, solvent extractables, PCBs, DDT and its metabolites) in sediments from the eastern portion of the reservoir coincided in many instances with a higher proportion of fine-grained material. Although this area is closest to the point of input or withdrawal (Figure 3) and one would expect sediments furthest from this point (stations 5-7) to have the highest proportions of fine-grained material, it is possible that the morphometry and cyclical use of the reservoir combine to counteract this tendency. During periods of high use, water pumped up into the reservoir over a period of 8 hours (eg. 11 p.m. - 7 a.m.) is withdrawn over the following 16 hours (eg. 7 a.m. - 11 p.m.). This means that fine particulate sediments in the influent water could only have a limited time to settle out of the water column enough to be beyond the influence of the drawdown, and so a certain proportion of these particles may leave the reservoir again and be carried into the lower Niagara River via the Sir Adam Beck power plant tailraces. Furthermore, the eastern end of the reservoir is considerably deeper than the western portion (Figure 4). Since the water level, which normally varies about 7.5 m (ie. from about 625' to 600' on Figure 4) during a cycle can vary up to 9 m (J.C. Sands, Ontario Hydro, personal communication), less than half the area is submerged at minimum water level (H-EPCO, 1961). This suggests that fine-grained material settling out in the western (and particularly the south-western) end would be more susceptible to disturbance and resuspension than in the eastern portion, particularly when withdrawal of water coincides with intense wave activity. In such cases, resuspended fines with their associated contaminants may reach the lower Niagara River via the power plant tailraces, or may resettle in the reservoir if time permits.

Over the past few years, the hydro-electric capacity of the reservoir has not been utilized as frequently as originally intended (J.C. Sands, Ontario Hydro). This would allow increased settling time of particulates and possibly decreased contributions to the lower Niagara River.

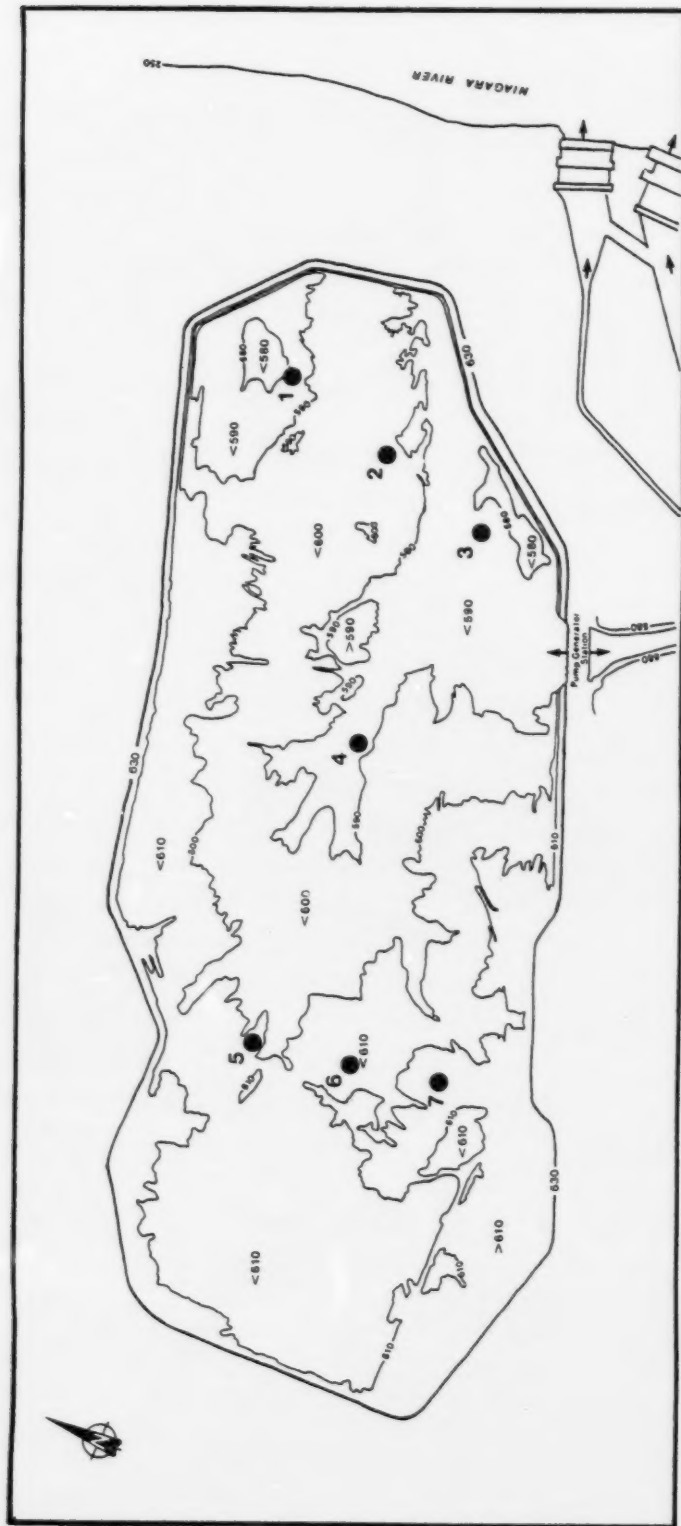


FIGURE 4 SIR ADAM BECK POWER RESERVOIR TOPOGRAPHY.

(Adapted from 1957 survey map, courtesy of Ontario Hydro, Design and Development-Generation Division, Geotechnology and Hydrology Engineering Department. Contours indicate elevation, in feet).

6.2 Niagara Bar Dredgeate

Nutrients, inorganics, solvent extractables and PCBs in dredgeate sampled at the Queenston dredge pile were considerably below the current MOE guidelines for the open water disposal of dredgeate (compare Tables 1 to 3 and 4).

With the exception of lead and selenium, mean concentrations of inorganics in dredgeate samples were 50% or less than the corresponding levels in fresh surficial sediments collected from the Niagara Bar. They were also considerably below the mean concentrations observed in bottom sediments from the lower Niagara River and the reservoir (Table 5).

Hexachlorobenzene was the only organochlorine detected (at 2 ng/g in 1 of 3 samples) in dredgeate from the Niagara Bar. This compound was detected more frequently and at higher levels in sediments from the lower Niagara River and Bar (Tables 3 and 4). Dieldrin, p,p'DDE and PCBs were detected in samples of bottom sediment from the Bar but not in dredgeate. BHC, mirex and alpha-endosulfan, organochlorine pesticides that were detected in sediments from the lower Niagara River in 1983 (Table 5), were not found in either sediment or dredgeate samples from the Niagara Bar.

The generally lower concentrations (and in certain instances, absence) of inorganic and organochlorine contaminants in Niagara Bar dredgeate samples than in fresh surficial sediments from the Bar coincides with the low proportion of fines in the dredgeate (average: 5.5% in the <62 μm diameter fraction) as opposed to the actual sediments (average: 18.5%). Since most contaminants are associated with fine particles, their lowered concentrations in dredgeate suggests some loss of fine materials during the dredging or storage stages. Such losses (eg. dewatering of dredgeate on board the vessel) may have local impacts on water quality.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Sir Adam Beck Power Reservoir

The presence of elevated concentrations of inorganic contaminants, as well as the pesticide DDT and its metabolites, in the Sir Adam Beck Power Reservoir sediments indicates the influence of upstream sources. Since the reservoir's clay liner precluded coring, it was not possible to determine any temporal trends in loadings to the reservoir. Nevertheless, the contaminants were identified in surficial layers, indicative of either relatively recent or ongoing inputs.

The exact sources of these contaminants is unclear at present. However, since the water in the reservoir is mainly derived from the Chippawa-Grass Island Pool above the Horseshoe Falls, inputs to the Ontario mainland shore of the Chippawa Channel (point sources and tributaries) are implicated. In contrast, the majority of Welland and Niagara Falls area point source discharges are included in the flow of the Queenston-Chippawa Power Canal, most of which goes directly to the Sir Adam Beck power stations and is not stored in the reservoir (see Figure 3).

Recommendation 1:

Monitoring should be instituted for the identified contaminants to determine their current levels in waters entering and leaving the reservoir (i.e. during storage and drawdown) and to allow a calculation of net loadings to the lower river under the current operating regime and their significance relative to other point sources. This should include whole water and suspended solids sampling and analysis.

Similar monitoring should also be carried out on waters of the Queenston-Chippawa Power Canal and the Chippawa-Grass Island Pool to determine their relative contributions, and possibly the sources of contaminants to them (see Recommendation 3).

Recommendation 2:

Further work should be undertaken to determine the mobility of the reservoir sediments, their associated contaminants, and the potential magnitude of contaminant loadings to the lower Niagara River via the power plant tailraces should resuspension occur (i.e. are the reservoir sediments currently a sink, a source or both?). In view of the inability to take core samples, it may be worthwhile to deploy sediment traps within the reservoir.

Recommendation 3:

Available data on the Welland River and Chippawa Creek, and on effluent characteristics from Fort Erie, Niagara Falls and Welland, Ontario point sources should be reviewed. If necessary, additional effluent samples should be obtained to identify the major contributors of the identified contaminants and to assess the need for additional restrictions, in line with the Ministry's recently-formulated municipal and industrial strategy for abatement (MISA) of point source discharges (MOE, 1986).

Recommendation 4:

In addition to possible effluent work, studies should be conducted within the watershed (e.g. Ontario tributaries to the upper Niagara River and to the Welland River) to aid in identification and elimination of sources of DDT. This would include a review of pesticide use, of tributary data and if necessary, sampling of whole water and suspended particulates (centrifugation). It is suggested that chemical analysis include dicofol.

7.2 Niagara Bar Dredgeate

The low concentrations of nutrients, inorganics, solvent extractables and virtual absence of organochlorines in dredgeate samples from the Queenston sand piles reflects the low proportions of fine-grained material. Contaminant concentrations were also well below available

MOE dredged material disposal guidelines, indicating relatively clean material. However, it should be noted that there are currently no available guidelines specifically dealing with contaminant concentrations in dredgeate used for sand and gravel.

Fresh surficial sediments obtained from the Niagara Bar in the vicinity of the dredging area contained higher proportions of fine-grained material (silts and clays) and associated contaminants. Some of the latter (eg. PCBs, iron) exceeded available dredging guidelines, which would preclude their open water disposal, while others (eg. hexachlorobenzene) have no currently available guidelines. These particulate-associated contaminants may become available to biota through resuspension during the dredging and dewatering operation.

Recommendation 5:

Monitoring of the sediment dredging operation on the Niagara Bar should be undertaken to ensure that there are no adverse effects on local water quality. This could be accomplished by the collection of suspended particulates in any turbidity plumes detected.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following:

- Mr. M. Vreugdenhil, formerly Ontario Hydro's Niagara District Mechanical Maintenance Superintendent, for providing access to the Sir Adam Beck Power Reservoir.
- Messrs. A.W. McLarty and A.G. Thachuk of the Ministry's West Central Region office in Hamilton for contributions to the survey design, arranging field logistics and equipment, and along with Ms. T. Lomas of the Ministry's Aquatic Contaminants Section in Toronto, collection of the reservoir and dredge pile samples.
- Staff of the Trace Organics and Inorganic Trace Contaminants Sections of the Ministry's Rexdale laboratories for analysis of samples.
- M. Kirby and S. Agnew of the Great Lakes Section for statistical analysis of the data.
- S. M. Irwin and A.W. McLarty (West Central Region), J. Viirland (Niagara River Improvement Project) and F.C. Fleischer and D. Boyd (Great Lakes Section) for constructive comments and suggestions on the draft report.
- A. Foley for typing the final manuscript and tables.

This study was funded in part by Environment Canada under the terms of the Canada-Ontario Agreement on Great Lakes Water Quality.

9.0 REFERENCES

- Choi, W.-W. and Chen, K.Y. 1976. Associations of chlorinated hydrocarbons with fine particles and humic substances in nearshore surficial sediments. *Environ. Sci. Technol.*, 10: 782-786.
- Förstner, U. and Wittmann, G.T.W. 1983. Metal Pollution in the Aquatic Environment. Springer-Verlag, New York.
- Frank, R., Thomas, R.L. Holdrinet, H., McMillan, R.K., Braun, H.E. and Dawson, R. 1981. Organochlorine residues in suspended solids collected from the mouths of Canadian streams flowing into the Great Lakes 1974-1977. *J. Great Lakes Res.*, 7: 363-381.
- Friesen, B.F. 1979. The international sharing of Niagara River hydro-electric power diversions. *Can. Water Res. J.*, 4:26-38.
- Hart, C.J. 1986. 1983 Niagara River Tributary Survey. Final Report submitted to Ontario Ministry of the Environment, Water Resources Branch, June 25, 1986. Toronto, Ontario.
- Håkanson, L. 1984. Sediment sampling in different aquatic environments: Statistical aspects, *Water Res. Res.*, 20:41-46.
- Hydro-Electric Power Commission of Ontario (1961). The Sir Adam Beck-Niagara Generating Station No. 2. A Major Canadian Hydro-Electric Power Development Near Niagara Falls, Ontario. Report based on paper by R.L. Hearn presented in London, England, May 16, 1956 to the Institution of Electrical Engineers, revised and reprinted October, 1961.
- Kauss, P.B. 1983. Studies of trace contaminants, nutrients and bacteria levels in the Niagara River. *J. Great Lakes Res.*, 9:249-273.
- Kuntz, K.W. 1984. Toxic Contaminants in the Niagara River, 1975-1982. Environment Canada Tech. Bull. No. 134, Inland Waters Directorate, Burlington, Ontario.

- Lum, K.R. and Gammon, K.L. 1985. Geochemical availability of some trace and major elements in surficial sediments of the Detroit River and western Lake Erie. J. Great Lakes Res., 11: 328-338.
- Moore, J.A. 1984. EPA proposal to cancel registration of dicofol products. Chem. Reg. Reporter, October 12, 1984, pp. 799-806.
- Mudroch, A. 1985. Geochemistry of the Detroit River sediments. J. Great Lakes Res., 11:193-200.
- Muir, D.C.G. and Yarechewski, A.L. 1984. Degradation of methoxychlor in sediments under various redox conditions. J. Environ. Sci. Health, B19: 271-295.
- Niagara River Toxics Committee. 1984. Report of the Niagara River Toxics Committee. Chapter VII: Recommendations for Long Term Monitoring. October, 1984. Toronto, Ontario.
- Ontario Ministries of the Environment and Natural Resources. (1986). Guide to Eating Ontario Sport Fish. Toronto, Ontario.
- Ontario Ministry of the Environment. 1976. Facts about pesticides. The history of DDT in Ontario. Fact Sheet No. 10-01-02, January 20, 1976. Toronto, Ontario.
- Ontario Ministry of the Environment. 1986. Municipal-Industrial Strategy for Abatement (MISA). A Policy and Program Statement of the Government of Ontario on Controlling Municipal and Industrial Discharges into Surface Waters. June, 1986. Toronto, Ontario.
- Ontario Ministry of the Environment. 1986. Guidelines for the Management of Dredged Material in Ontario. Draft Report, May, 1986. Toronto, Ontario.
- Ontario Ministry of the Environment. 1983. Water Quality Data-Ontario Lakes and Streams. Water Resources Branch, unpublished data. Toronto, Ontario.

- Ontario Ministry of the Environment. 1983. Handbook of Analytical Methods for Environmental Samples. Laboratory Services and Applied Research Branch. December, 1983, Toronto, Ontario.
- Ontario Ministry of the Environment. 1982. Ontario Guidelines for Classification of Pesticide Products. Pesticides Advisory Committee. May, 1982, Toronto, Ontario.
- Persaud, D. and Wilkins, W.D. 1976. Evaluating Construction Activities Impacting on Water Resources. Ontario Ministry of the Environment Report. January, 1976, Toronto, Ontario.
- Sly, P.G. 1983. Sedimentology and geochemistry of recent sediments off the mouth of the Niagara River, Lake Ontario. J. Great Lakes Res., 9:134-159.
- Verschueren, K. 1983. Handbook of Environmental Data on Organic Chemicals, second edition. Van Nostrand Rheinhold Company, New York.

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